1. REFERENCE NETWORKS

1.1. INTRODUCTION

This part of the Polish National Report on Geodesy is the quadrennial report on positioning works performed in Poland in a period 1999-2002. It summarises the state of art of Polish national zero-order geodetic control network, permanent GPS stations operating in Poland, active GPS/DGPS station network in Poland, vertical network, Polish national gravity control network, etc. The activities concerning reference networks were conducted mainly at the following research centres, listed in an alphabetic order:

- Chair of Satellite Geodesy and Navigation, University of Warmia and Mazury in Olsztyn;
- Department of Geodesy and Geodynamics, Institute of Geodesy and Cartography in Warsaw;
- Department of Geodesy and Photogrammetry, Agricultural University in Wroclaw;
- Department of Mining Surveying and Environmental Engineering, University of Mining and Metallurgy in Cracow;
- Department of Planetary Geodesy, Space Research Centre, Polish Academy of Sciences in Warsaw;
- Institute of Geodesy, University of Warmia and Mazury in Olsztyn;
- Institute of Geodesy and Geodetic Astronomy, Warsaw University of Technology.

The content of the chapter is based on the material prepared by Stefan Cacon, Wladyslaw Goral, Jan Krynski, Adam Lyszkowicz, Stanislaw Oszczak, Wojciech Pachelski, Jerzy B. Rogowski, Andrzej Sas-Uhrynowski and Janusz B. Zielinski.

The bibliography of the related works is given in references.

Annual national reports to the IAG Sub-commission for EUREF (Baran et al., 2000; Pazus, 2002; Krynski et al., 2002) contain the extensive information on the activities concerning reference networks in Poland within the reported period.

1.2. MAINTENANCE OF EUREF-POL NETWORK

Following the recommendation of the EUREF Technical Working Group (Report of the EUREF Technical Working Group, 1999) the Head Office for Geodesy and Cartography in Poland confined to the Department of Planetary Geodesy of the Space Research Centre, Polish Academy of Sciences, in 2001, to re-survey the EUREF-POL network. The second EUREF-POL campaign was conducted in 26-30 September 2001. The same set of 11 stations as in the first EUREF-POL campaign was re-surveyed. One EUVN network station was also included in the campaign. The survey was conducted with Trimble 4000SSi receivers in five 24h sessions. The observations collected during the campaign were processed at the Department of Planetary Geodesy of the Space Research Centre, Polish Academy of Sciences, using Bernese v.4.2 software. The network was computed in the ITRF2000 reference frame for 2001.74 epoch and the results were transformed to the ETRS89. The comparison of results of the first and recent campaigns shows that the network is stable within the limits of accuracy of the epoch 1992. Estimated average differences in coordinates equal to ±3 mm (north), ±5 mm (east) and ±10 mm (up). Monumentation of the EUREF-POL stations proved to be robust and reliable.

Two permanent stations where antennas were modified show the difference of 20 mm in height. The coordinate differences obtained at the stations are listed in Table 1.1. A number of comparisons have been done between this solution and the solutions for POLREF network and the EUVN network (Jaworski et al., 2002). The EUREF-POL 2001 campaign demonstrated that the national geodetic system for Poland that is based on the EUREF-POL 92 solution is good enough for all practical purposes and needs no substantial modifications.

Table 1.1. Comparison of results of EUREF-POL 92 and EUREF-POL 2001 campaigns

Station	ΔLat [mm]	ΔLon [mm]	Δh [mm]
0216 BOROWIEC (BOR1 12205M002)	1.7	-4.0	4.5
0217 BOROWA GORA (BOGI 12207M003)	5.4	-3.6	20.0
0301 ROZEWIE	-1.3	4.7	-6.6
0302 LAMKOWKO (LAMA 12209M001)	-4.8	8.5	19.2
0303 MASZE	5.2	-6.7	14.0
0304 CZARNKOWIE	2.5	3.1	-4.3
0306 JOZEFOSLAW (JOZE 12204M001)	-4.6	-8.6	-10.0
0307 STUDNICA	1.0	3.0	13.6
0308 ROGACZEW	-0.2	3.7	-16.1
0309 ZUBOWICE	-1.8	4.9	1.2
0310 GRYBOW	-2.5	-0.1	3.9

1.3. OPERATIONAL WORK OF PERMANENT IGS/EUREF STATIONS

Permanent GPS stations of IGS and EUREF networks operate in Poland since 1993. The number of GPS stations in Poland was growing within last years. Recently 8 permanent GPS stations, i.e. Borowa Gora (BOGO, BOGI), Borowiec (BOR1), Jozefoslaw (JOZE, JOZ2), Lamkowko (LAMA), Krakow (KRAW) and Wroclaw (WROC) (Fig. 1.1) are in operation in Poland within the IGS/EUREF program (Table 1.2). A brief characteristic of those stations is given in Table 1.3. Products of the permanent GPS stations in Poland, together with such stations in Europe, were the basis of the networks that are applied for both research and practical use in geodesy, surveying, precise navigation, environmental projects, etc. Data from those stations is transferred via Internet to the Local Data Bank for Central Europe at Graz, Austria and to the Regional Data Bank at Frankfurt/Main, Germany. The EPN stations at Borowa Gora, Borowiec, Jozefoslaw and Wroclaw participate in IGS/IGLOS program. Jozefoslaw and Krakow stations take part in the EUREF IP pilot project (Table 1.4) (http://www.epncb.oma.be/projects/euref_IP/euref_IP.html).

Table 1.2. Permanent GPS stations in Poland

Name (abbr.)	Latitude	Longitude	Status	Receiver
Borowa Gora (BOGI)	52°28’30’’	21°02’07’’	IGS, EUREF	Javad JPS Eurocard
Borowa Gora (BOGO)	52°28’33’’	21°02’07’’	EUREF	Ashtech Z-12
Borowiec (BOR1)	52°16’37’’	17°04’27’’	IGS, EUREF	Turbo Rogue SNR 8000
Jozefoslaw (JOZE)	52°05’50’’	21°01’54’’	IGS, EUREF	Trimble 4000 SSE
Jozefoslaw (JOZ2)	52°05’52’’	21°01’56’’	IGS	Ashtech Z-18
Krakow (KRAW)	50°03’58’’	19°55’13’’	EUREF	Ashtech μZ-12
Lamkowko (LAMA)	53°53’33’’	20°40’12’’	IGS, EUREF	Ashtech Z-12 Turbo Rogue SNR 8000
Wroclaw (WROC)	51°08’48’’	17°03’43’’	EUREF	Ashtech Z-18

Fig. 1.1. IGS/EUREF network of permanent stations in Poland

Table 1.3. Characteristics of Polish EPN stations

4 char Station ID	Domes Number	**Location**/ Institution	**Receiver**/ Antenna	Started operating	**Meteo**/ Rec. device	Data transfer blocks	Additional observations
BOGO	12207M002	**Borowa Gora** Inst. of Geodesy and Cartography	**Ashtech ZXII3** ASH700936C_M SNOW	08JUN1996	**Yes** LAB-EL Poland	24 h 1h	Ground water level Astrometry Gravity GPS
BOGI	12207M003	**Borowa Gora** Inst. of Geodesy and Cartography	**Javad JPS Euro-card** ASH700936C_M SNOW	06MAY2003	**Yes** LAB-EL Poland	24 h 1h	Ground water level Astrometry Gravity GPS/GLONASS
BOR1	12205M002	**Borowiec** Space Research Centre, PAS	**Rogue SNR-8000** AOAD/M_T	01JAN1994	**Yes** NAVI Ltd. Poland	24 h 1h	SLR GPS/GLONASS
JOZE	12204M001	**Jozefoslaw** Inst. of Geodesy and Geod. Astr., WUT	**Trimble 4000SSE** TRM14532.00	03AUG1993	**Yes** LAB-EL Poland NAVI Ltd. Poland	24 h 1h	Ground water level Astrometry Gravity tidal GPS
JOZ2	12204M002	**Jozefoslaw** Inst. of Geodesy and Geod. Astr., WUT	**Ashtech Z18** ASH701941.B SNOW	02JAN2002	**Yes** LAB-EL Poland NAVI Ltd. Poland	24 h 1h	Ground water level Astrometry Gravity tidal GPS/GLONASS
KRAW	12218M001	**Krakow** AGH UST	**Ashtech μZ-12** ASH701945C_M SNOW	01JAN2003	**Yes** LAB-EL Poland	24 h 1h	GPS
LAMA	12209M001	**Lamkowko** Inst. of Geodesy, UWM	**Ashtech ZXII3** ASH700936F_C SNOW	01DEC1994	Yes LAB-EL Poland	24 h	Gravity GPS
WROC	12217M001	**Wroclaw** Agriculture Academy	**Ashtech Z18** ASH700936D_M	28NOV1996	**Yes** LAB-EL Poland	24 h 1h	Ground water level GPS/GLONASS

Table 1.4. Characteristics of Polish stations participating in the EUREF IP pilot project

Location	Appr. Lat. [deg]	Appr. Long. [deg]	RTCM message types (update rate [s])	Bitrate [bits/s]	Site log file
Krakow	50.01	19.92	1(1), 3(30), 16(60), 18(1), 19(1), 22(60)	1900	KRAW
Jozefoslaw	52.10	21.03	1(1), 3(60), 18(1), 19(1), 22(60), 31(1)	1200	JOZ2

1.4. ACTIVE GPS/DGPS STATION NETWORK IN POLAND

The study group appointed in 1995 by the Polish Academy of Sciences recognised that the number of active multifunctional permanent GPS stations in Poland should be increased in the future. The distances between stations should amount about 50 km. The stations should form a new generation geodetic network, adequate for many social and economical needs. The local analysis centres in co-operation with national analysis centre should be engaged in processing of the permanent GPS observations. Conditions and limitations of using permanent GPS stations in common geodetic practice as well as in navigation were discussed (Dobrzycka et al., 1999; Oszczak et al., 1999a, 2000; Manzoni and Oszczak, 2000)

The technical project of ASG-PL network, ordered by the Head Office for Geodesy and Cartography in Poland, was reviewed by the study group (Baran et al., 2000b; 2000c). A sub-network of the ASG-PL with data processing centre was established in Upper Silesia by the end of 2002, as a pilot project of governmental and local (regional Silesian) authorities and it has reached a preliminary operational stage in February 2003. The map of this network is given in Fig. 1.2. The network consists of 6 permanent stations and is recently linked to EPN (BOGI, BOGO, JOZE, KRAW, LAMA, WROC) stations and two other permanent GPS stations (CBKA, INS1) (Fig. 1.4) that provide GPS data at 5 s sampling rate. Network stations are equipped with Ashtech µZ-12-CGRS receivers with ASH701945C_M SNOW antennas. Observations are made at 5 sec sampling rate and are transferred to the processing centre hourly.

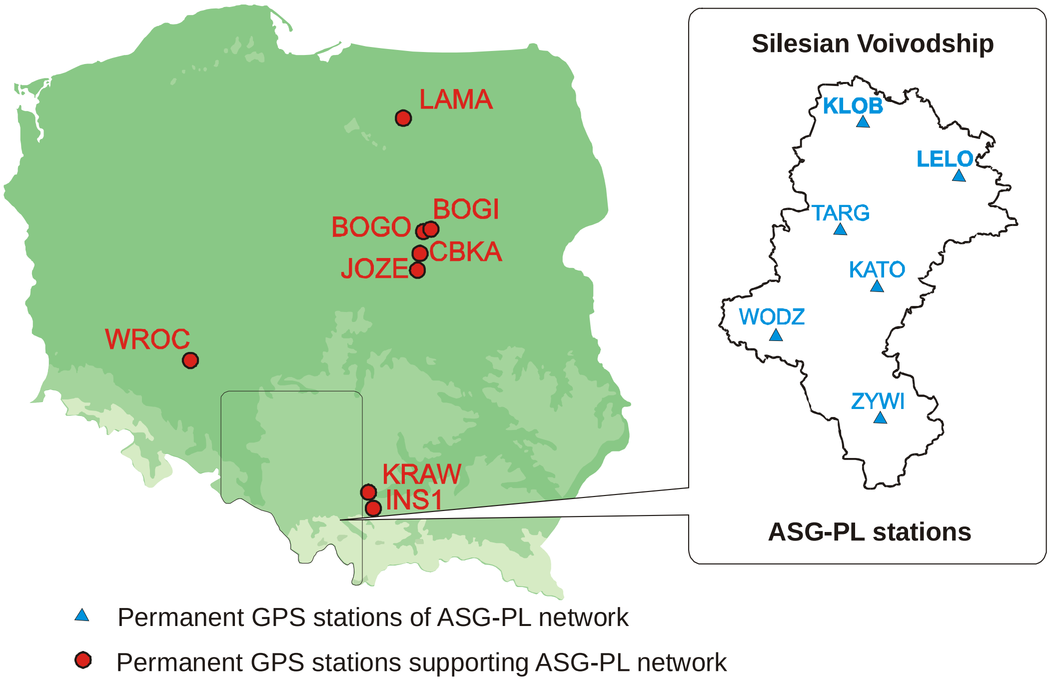

Fig. 1.2. Map of the operating in 2003 part of the Polish Active Control Network

The system of automatic processing of GPS data for ASG-PL network designated for the users is under testing.

1.4.1. DGPS/RTK Reference Stations

DGPS Maritime Navigational Service System

Two permanent reference DGPS stations: Dziwnow and Rozewie, equipped with 12-channel GPS receivers, complement the Baltic Sea maritime navigational network of stations along Polish seashore. Since 1995 they distribute the RTCM corrections on radio frequency. Redundancy of the equipment controlled by a computer system is provided in order to maintain high total hardware reliability and to ensure continuity of broadcasting. Local Integrity Monitor for faults and automatic change for hot stand-by blocks continuously monitor functioning of equipment. Data is accessible via telephone line modems for remote monitoring, controlling and alarm reporting purposes. The transmission is broadcast with MSK modulation in the band allocated for marine radio-navigation Region A1 (283.5-315 kHz). Both stations include second carrier emission spaced by 500 Hz to maintain RDF service when necessary. Assigned frequencies, nominal ranges for signal strength 34 dB (50µV/m) are shown in Table 1.5.

Table 1.5. DGPS broadcast stations in the Southern Baltic seashore

Station name	Function	Position	ERP [W]	Nominal Range [50µV/m]	Frequency [kHz]	Bit rate [Bit/s]	Emission	RTCM Message Type	ID code ID no	Antenna
Dziwnow	RDF DGPS	54°01' N 14°44' E	0.1	90 90	287.5 288.0	- 100	100HA1ABN 100HG1DCN	- 1,2,3,7,16	DZ 481	vertical mast
Rozewie	RDF DGPS	54°49' N 18°20' E	0.4	90 90	310.5 311.0	- 100	100HA1ABN 100HG1DCN	- 1,2,3,7,16	RO 482	horizontal 2T

Technical characteristics conform to standard adopted by ITU-R in Recommendation M.823 including data and message format based on RTCM SC 104 Version 2.0 standard. Data transmission is continuous with 100-baud rate; class of emission is G1D (digital with phase modulation). Maximum occupied bandwidth is less than 130 Hz. Transmitters coupled to omni-directional antennas share the nominal 100W output power for direction finding signal and DGPS data transmission.

Static accuracy of order of 1.5–3 m (95%) is provided by the DGPS service depending on the distance and propagation conditions. Radius of coverage of sea area for Rozewie and Dziwnow stations is practically about 120 km and 80 km, respectively.

DGPS/RTK Reference Station Local Network of Three-City Area Gdansk, Sopot, Gdynia

The project run by the Polish Committee of Scientific Research, the Gdansk Voivodship and the University of Warmia and Mazury in Olsztyn resulted in establishing the DGPS/RTK Reference Station Local Network for Gdansk, Sopot and Gdynia Metropolitan. The system is designated to support GPS surveying in the region (positioning for surveying, GIS data acquisition, cadaster modernization, etc.) as well as to land and sea navigation, in particular for augmentation of emergency and civil town services (police, fire brigades, first aid and ambulance services, transportation, etc.), real-time positioning and navigation, as well as bathymetric surveying. It consists of 3 reference stations, one in each city mentioned. Each reference station is equipped with Ashtech Z-FX dual frequency P-code GPS receiver with DGPS and RTK options. A computer, a system of radio-transmission of correction data, modems and transmission system to provide mutual connection between stations, make the complementary infrastructure of each reference station.

The Master Station monitors operation of reference stations, collects raw data from reference stations and monitors integrity. All reference stations process data and broadcast DGPS and RTK messages in RTCM 104 v.2.1 standard format as well as process users data. The link between reference stations and user receivers is held using radio link at frequency of about 450 MHz with 1 W transmission power. The system became fully operational in 2001.

DGPS Reference Station of the Institute of Geodesy and Cartography, Warsaw

Since April 1998, the Ashtech Dorne Margolin GPS antenna of BOGO station is used by a permanent DGPS station at Borowa Gora, run by the Ashtech G-12 receiver. The RTCM 104 messages with DGPS corrections are transmitted via a system consisting of a GSM cellular phone and a modem (Cisak et al., 2000a).

In October 1999 in the Institute of Geodesy and Cartography in the city centre of Warsaw there was installed another reference DGPS/RTK station equipped with the receiver Z-12 Sensor and a NAVI software; also the mobile phone system Plus GSM is used (Cisak et al., 2000b). The research on the use of RTK – GSM surveying in urban area is in progress.

DGPS Reference Station of the Space Research Centre, Warsaw

DGPS Reference Station operates at the Space Research Centre of the Polish Academy of Sciences in Warsaw. It has been established as a base station for the research project on DGPS surveying in urban areas with use of mobile GPS laboratory. The differential corrections are broadcast once a day during one-hour period. The operational range of the network depends on radio propagation conditions and reaches about 3 to 5 km away from the base station.

1.4.2. Some Applications of DGPS/RTK Techniques

Chair of Satellite Geodesy and Navigation, Olsztyn University of Warmia and Mazury

Since 1997 the University of Warmia and Mazury in Olsztyn has been engaged in experimental works on application of DGPS service for the needs of Gdansk agglomeration. Three multifunctional DGPS and RTK reference stations were established in Gdansk, Sopot and Gdynia (Oszczak et al., 1999).

Some experimental works on accuracy of real-time DGPS and RTK positioning were carried out (Bakula and Oszczak, 2000; Ciecko and Oszczak, 2000). In particular, the joint project of the University of Warmia and Mazury, Olsztyn, and the Military School of Airforce, Deblin, on testing RTK for navigating the flight of the jet aircraft equipped with GG24 receiver as well as its landing, was conducted. Aircraft trajectory determination using DGPS and RTK techniques as well as its accuracy was analysed (Ciecko et al., 2002a, 2002b; Grzegorzewski et al., 2000, 2001a, 2001b, 2001c, 2002).

Institute of Geodesy and Cartography, Warsaw

Three receivers of the Institute of Geodesy and Cartography, Warsaw, took part in the joint project of the University of Warmia and Mazury, Olsztyn and the Military School of Air force, Deblin. The project was designated to testing RTK for navigating the flight of the jet aircraft equipped with GG24 receiver as well as its landing. Two receivers located at the Geodetic-Geophysical Observatory at Borowa Gora and one on the roof of the Institute of Geodesy and Cartography at Warsaw were used as base stations for the RTK survey during five flights. The experiment lasted for 5 days. Data collected during the experiment were post-processed. The results of the experiment were published.

RTK with GSM data transfer was extensively tested at the Institute of Geodesy and Cartography, Warsaw. Test surveys with Ashtech GPS receivers were conducted in urban area as well as at the sites with no obstructions. Internal accuracy of RTK was tested as well as its dependence on the distance from the base station. The superiority of GSM data transfer in RTK over conventional radio link was indicated. The results of the experiments as well as practical recommendations were presented (Cisak et al., 2001)

Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology

Some Polish institutions have designed and established active DGPS stations that can operate upon request. The Institute of Geodesy and Geodetic Astronomy of the Warsaw University of Technology installed at the Astro-Geodetic Observatory in Jozefoslaw the Trimble 4000 CORS Station with a mobile phone system for distribution of DGPS corrections in RTCM 104 format (Bogusz J., at all 2000, 2001a, 2001b). In 1999 another experimental station was established in the centre of Warsaw on the top of the main building of the University. The experience gained by Polish institutions will be used in creating Polish GNSS system operating in RTK/post processing modes for geodetic and land, air and marine navigation purposes. Such a system based on about 70 active multifunctional reference stations is now developed in Poland in the frame of international project EUPOS (European Position Determination System) (Sledzinski and Albin, 2002).

1.5. VERTICAL NETWORK

1.5.1. Re-levelling of the Vertical Control Network in Poland

In 1999-2002 the 1st order Vertical Control Network in Poland was re-surveyed (Pazus, 2002). It is the 4th precise levelling campaign in history of Poland (Table 1.6).

Table 1.6. Levelling campaigns of the 1st order precise levelling network in Poland

Epoch	Duration	Total length of lines	Comments
1st campaign 1927-1937	12 years	10 046 km	Vertical datum: „Normal Null" Amsterdam by the reference benchmark in the wall of the Town Hall in Torun
↕ 20 years			
2nd campaign 1947-1950 1952-1955	9 years	4 403 km 5 778 km	Levelling in western and north-eastern Poland as an extension of the 1st campaign within new borders of Poland
↕ 19 years			
3rd campaign 1974-1979 (UPLN) 1952-1955	9 years	10 438 km 17 015 km	rms of differences between fore and back (sections) 0.29mm/km rms of differences between fore and back (lines) 0.55mm/km rms of closing loops 0.92mm/km Lallemand formula random error 0.40mm/√km systematic error 0.10mm/km included 10 438 km of UPLN
↕ 17 years			
4th campaign 1999-2002	4 years	17 015 km	Re-levelled benchmarks of the 3rd campaign. No changes in the location of levelling lines.

The particularities of the 4th levelling campaign in Poland are given in Table 1.7 (Pazus, 2002).

Table 1.7. The 4th levelling campaign in Poland 1999-2002

	Number	**Average length**
Loops	135	221 km
Lines	371	46 km
Sections	~16 000	1.1 km
Total length of lines 17 015 km		
Levels used		
Automatic Ni002 – Zeiss (9 field teams)	Digital DiNi – Zeiss (4 field teams)	Digital NJ – Topcon (2 field teams)
Staves used on iron spikes		
3 m strip of invar (double-scaled in 0.5 cm)	Coded staves	Coded staves
Field procedure		
Double levelling (fore & back) with length of site up to 40 m Reading sequence: „back-fore-fore-back” and then „fore-back-back-fore” or „back-back-fore-fore”		

The map of the levelling lines, node points and computed misclosures including maximum acceptable misclosures in the loops is given in Fig. 1.3.

Fig. 1.3. Levelling lines and node points with computed misclosures

The results of preliminary analysis of closing errors in 135 loops of the network were presented to EUREF in 2002 (Krynski et al., 2002). Linking the network to the vertical control of neighbouring countries is in progress. First results of network adjustment are expected in July 2003.

1.5.2. Sea Level Changes

The PHASE software developed in the Space Research Centre of the Polish Academy of Sciences was used to determine geocentric positions of 9 points of the network in the south region of the Baltic Sea in two observation epochs, based on GPS measurements performed in 1993 and 1997 (the campaigns BSL'93 and BSL'97). The point positions were then used to determine ellipsoidal heights and height changes of the points, that together with other data can be a subject to geophysical analyses aiming at detailed description and interpretation of changes of the Baltic Sea level. The determined height changes should, however, be considered only as an initial information on possible tendencies of geotectonic movements in the region (known as Fennoscandian Land Uplift).

With the Baltic Sea Level Project terminated, the Department of Planetary Geodesy of the SRC PAS continues the research on sea level changes. It took part in the COST Action 40 "EOSS-European Sea-Level Observing System", where the scientific and technical foundation for the international service has been discussed and the final concept has been defined. Organisation of this service named ESEAS started in 2002 and the new GPS/Tide Gauge Station in Wladyslawowo was established (Zdunek et al., 2001).

1.5.3. Analysis of Levelling Campaigns in Poland

Poland has extensive records of precise levelling networks. Four primary levelling campaigns 1926-1937, 1947-1955, 1974-1982 and 1999-2002 were conducted. The adjustment of 4th levelling campaign in Poland (1999-2002) is now in progress. Data from the first and second campaigns were available in the hard copy archive. The database for that data was established in 2002 (Lyszkowicz et al., 2002).

Three precise levelling networks of Poland were selected as the subject of study of detecting the existence of non-random effects in levelling networks (Lewandowicz et al., 2002). Line discrepancies and loop misclosures from the first, second and third levelling campaigns were tested for normal distribution, rejection of observations and the absence of systematic errors. The tests did not reveal any systematic effects. The 3rd levelling campaign 1974-1982 was re-adjusted with use of new gravity data and with normal gravity referred to GRS80 ellipsoid (Gajderowicz, 1999). The results were compared with UELN and EUVN heights.

1.6. NEW GRAVITY NETWORK

New Polish gravity network was established in 1994-1998 (Sas-Uhrynowski et al., 2000). It consists of 354 gravity points with 12 absolute gravity stations (Fig. 1.4). All network points used for relative gravity measurements were monumented with the concrete pillars of size of 80×80×100 cm.

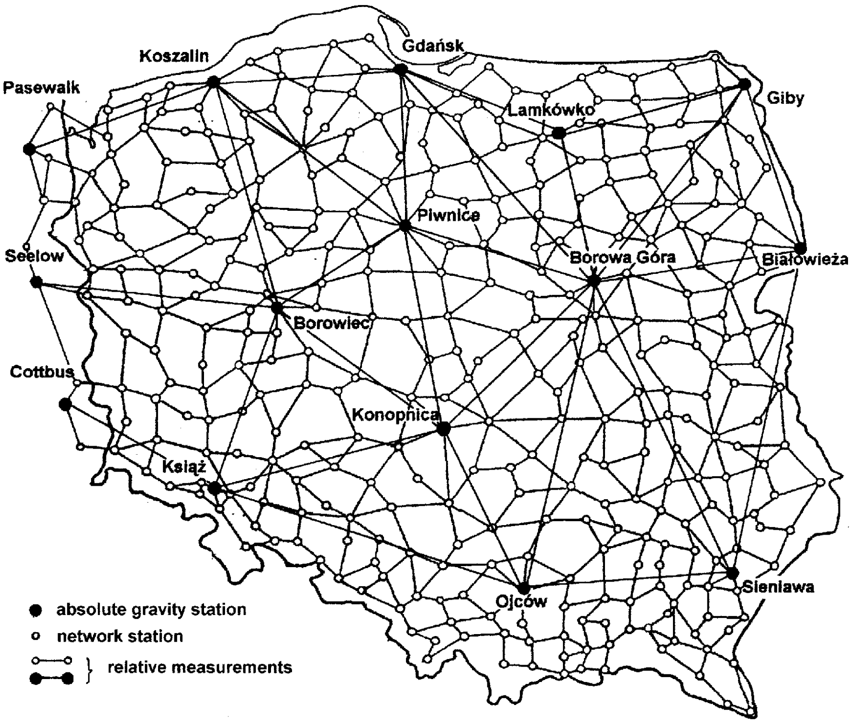

Fig. 1.4. The new Polish gravity network

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